RESONANCES IN THE RADIACTIVE CAPTURE OF PROTONS BY SULFUR-34

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ABSTRACT

This investigation was conducted to discover the resonance proton absorption energy levels for the $S^{34}(p,\gamma)Cl^{35}$ reaction between E_p of 800 kev and 1950 kev. The proton beam was produced by the two-Mev Van de Graaff generator at the U. S. Naval Postgraduate School. The information was obtained in the form of gamma yield vs. E_p.

The following proton capture resonance levels, not previously reported to the cognizance of the investigators, were discovered:

E_p (kev)	Relative Yield	Half-width (kev)
1015 ± 4	1.5	9
1206 ± 4	13.5	5
1523 ± 4	4.5	8

The low resonances at E_p of 1370, 1610, 1697, 1810, and 1860 kev, reported by Hanscome and Malich, were not definitely confirmed, though it is possible that they were observed without being conclusively identified.

The authors gratefully acknowledge the contributions of both theoretical advice and technical assistance provided by Professor Edmund A. Milne. Appreciation is also expressed for the technical assistance of Allen Goodall, Robert Moeller, and Kenneth C. Smith.

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1. Introduction

The Van de Graaff generator at the Naval Postgraduate School provides protons with energies up to 2 Mev. From the view of nuclear spectroscopy, protons of these energies are very suitable for experiments on (p,γ) reactions in lighter nuclei. These relatively low bombarding energies have two advantages: the de-excitation of a resonance level will be simpler, the lower the excitation energy; and the general background of gamma radiation is lower at lower bombarding energies. Because little was known of the S (p,γ)Cl reactions, they were selected for investigation.

A knowledge of the natural characteristics of the S (p,γ)Cl reactions is required for this investigation:

Isotope	Abundance	Q-Value for (p,γ)	Gamma ray energy for E_p = 830 to 1900 kev
S^{32}	95.1%	2.285	3.090 - 4.130 Mev
S^{33}	.74%	5.12	5.925 - 6.960
S^{34}	4.2%	6.373	7.178 - 8.213
S^{36}	.016%	8.46	9.265 - 10.30

The chlorine products resulting from the (p,γ) reactions with S^{34} and S^{36} are stable isotopes which de-excite promptly to ground state. However, the compound nuclides Cl^{33*} and Cl^{34*} are positron-emitters with the following decay schemes:

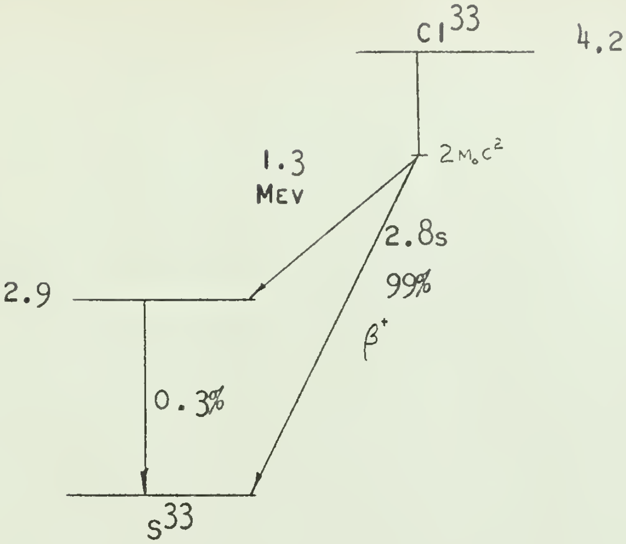


Figure 1. Decay Scheme of Cl^{33}

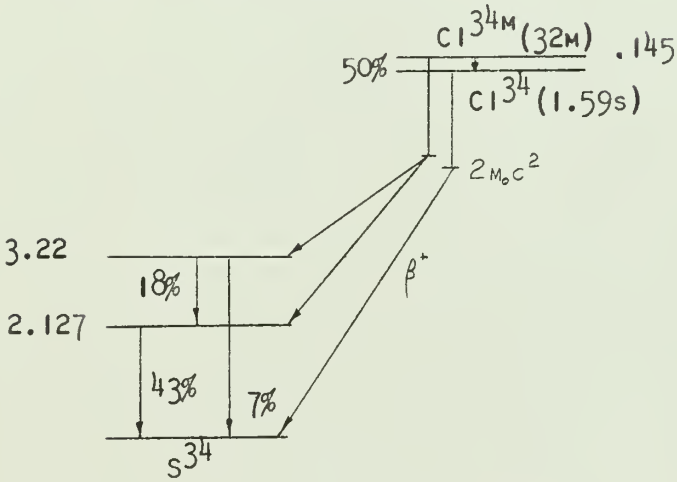


Figure 2. Decay Scheme of Cl^{34}

Little information is available concerning the cross-sections or relative yields for $S(p,\gamma)$ reactions. However, it is assumed that reactions with S^{36} will not be observable, since the abundance both in enriched and natural sulfur is exceedingly small.

It is expected that gamma yields from strong S^{33} reactions could be detected from bombardment of natural sulfur targets, with approximately the same yields as with the enriched S^{34} material, because of the similar proportions of S^{33} in the natural and the enriched sulfur. Figures 1 and 2 indicate that if reactions due to $S^{32} + p$ or $S^{33} + p$ were suspected, they could be distinguished from the $S^{34} + p$ reactions by investigating possible positron decay of the compound nuclides Cl^{33*} and Cl^{34*}.

2. Previous Investigations

Relatively little work has been reported regarding the proton-gamma reaction with isotopes of sulfur.

A comprehensive work over a limited energy range was performed by C. Van der Leun, Utrecht University, Utrecht, Netherlands. His experiments dealt with the proton-gamma reactions of isotopes S^{32} and S^{33}, with proton energies up to 800 kev (1).

A. $S^{32} + p$

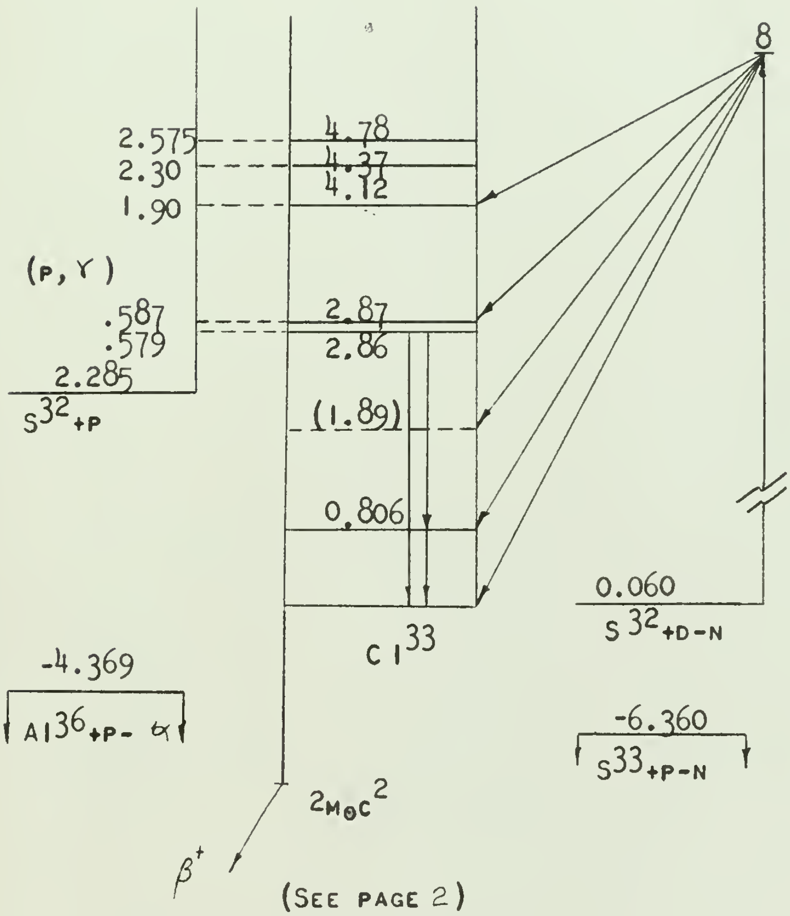
References as late as 1958 report that within the E_p = 200 to 800 kev region there is only one resonance at 594 kev. However, private correspondence with E.M. Endt reveals that there are two resonances at 579.8 ± 1.5 and 587.4 ± 1.5 kev (2). No other resonances of S^{32} have been found below 850 kev.

The region of E_p = 0.9 to 2.1 Mev has been investigated by T. D. Hanscome and C. W. Malich using the Van de Graaff generator at the Naval Research Laboratory (3,4). However, since no induced beta-activity was observed, all resonances were attributed to the $S^{34}(p,\gamma)Cl^{35}$ reaction.

Other investigations of sulfur include that of the $S^{32}(p,p)S^{32}$ reaction performed by A. J. Ferguson and H. E. Gove of the Chalk River Laboratories (5). With a H_2S gas target, two resonances were reported in the region E_p = 1.0 to 2.8 Mev at 1.9 and 2.31 Mev. The latter is beyond the energy range of this investigation, but the 1.9 Mev resonance was frequently observed. Recent work by J. W. Olness, W. Haeberli and H. W. Lewis of Duke University with $S^{32}(p,p)S^{32}$ and $S^{32}(p,p',\gamma)S^{32}$ reactions has confirmed the S^{32} resonances at 1.9 and 2.31 Mev (6). Their experiments incorporated a H_2S (99% pure) gas target and

covered the energy range of E_p = 1.5 to 4.0 Mev.

Figure 1 summarizes the results of previous investigations and indicates the excited levels of the resulting compound nucleus Cl^{33} (7).



(See page 2)

Figure 3. Resonance Levels of Cl^{33}

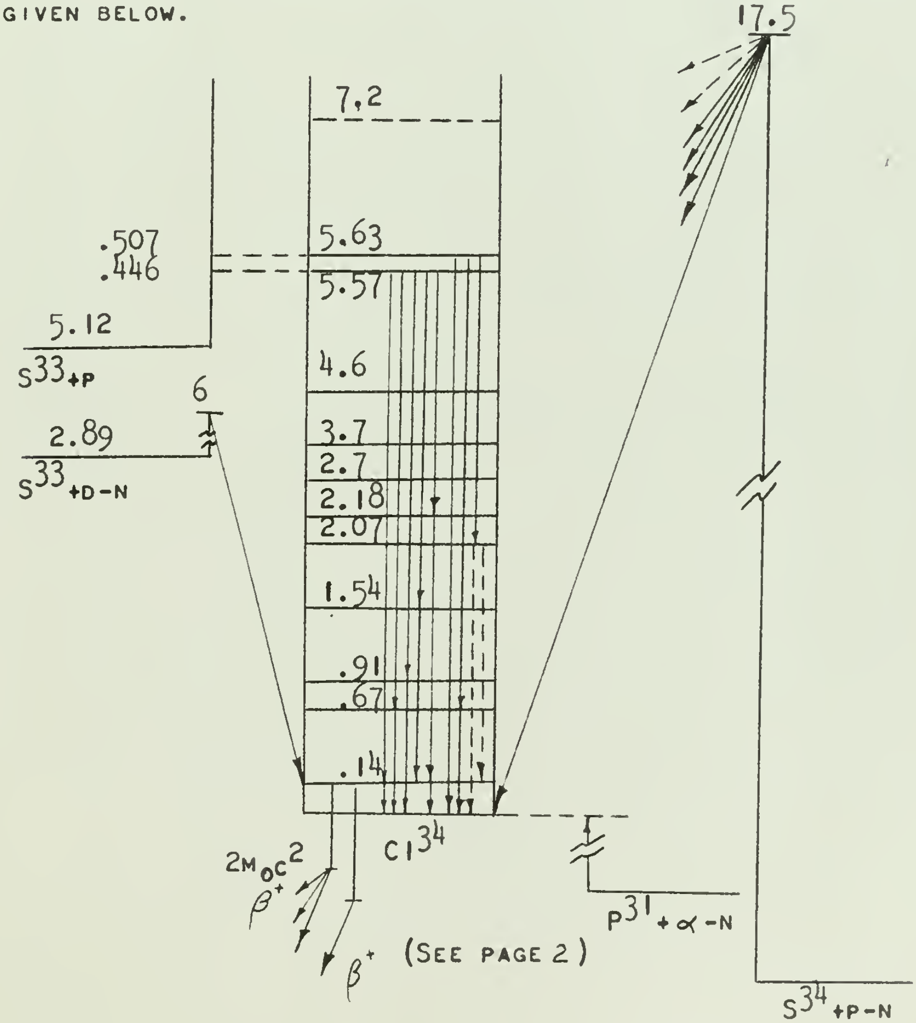
B. S^{33} + p

Since sulfur of natural isotopic composition is only .75% S^{33} and the enriched CdS^{34} obtained from the Oak Ridge Laboratories contained 0.8% S^{33}, an almost insignificant gamma yield can be expected. Concurrent investigations of this reaction are being conducted by A. H. Gaehler

and A. L. Knipp to determine excited levels of Cl^{34} in the region $E_p = 1.10 - 1.5$ Mev. and since their enriched CdS^{33} contains 73.6% S^{32} and 4.2% S^{34}, their results have been compared with the resonances observed in this investigation with CdS^{34}, in order to try to match the resonances with the proper isotope.

C. Van der Leun's investigations in the region of E_p = 200 to 850 kev show two resonances at 449 and 513 kev (1). However, these figures have been revised and are finally reported as 446.5 and 507.0 kev (2). Also seven new levels have been detected in Cl^{34}. Between E_p = 550 and 850 kev, at least ten more resonances are indicated in the $S^{33}(p,\gamma)Cl^{34}$ reaction.

A summary of known resonances resulting in the excited state of Cl^{34} is given below.



(See page 2)

Figure 4. Resonance Levels of Cl^{34}.

C. $S^{34} + p$

Little information regarding this reaction has been reported. P. M. Endt has observed several resonances in the E_p = 200 to 850 kev region, but resolution difficulties prevented exact resonance energy determinations (2). The region from E_p = .9 to 2.1 Mev, searched by T. D. Hanscome and C. W. Malich using cadmium sulfide of natural isotopic composition, has revealed numerous narrow resonances, many of which apparently are not easily resolved. Since no induced activity was observed, these resonances were attributed to S^{34}. The more prominent resonances were reported at E_p of 1.37, 1.61, 1.69, 1.81 and 1.86 Mev. Hanscome and Malich have observed relatively intense resonances above 1.9 Mev but again poor resolution prevented their exact location. Estimates of the gamma-ray energy coincided with calculated Q-values and some possible cascade transitions were observed. Work was discontinued in this region, however, because the equipment used by Malich and Hanscome was diverted to other uses.

A summary of the reported excited states of Cl^{35} is reported below (7). (See next page.)

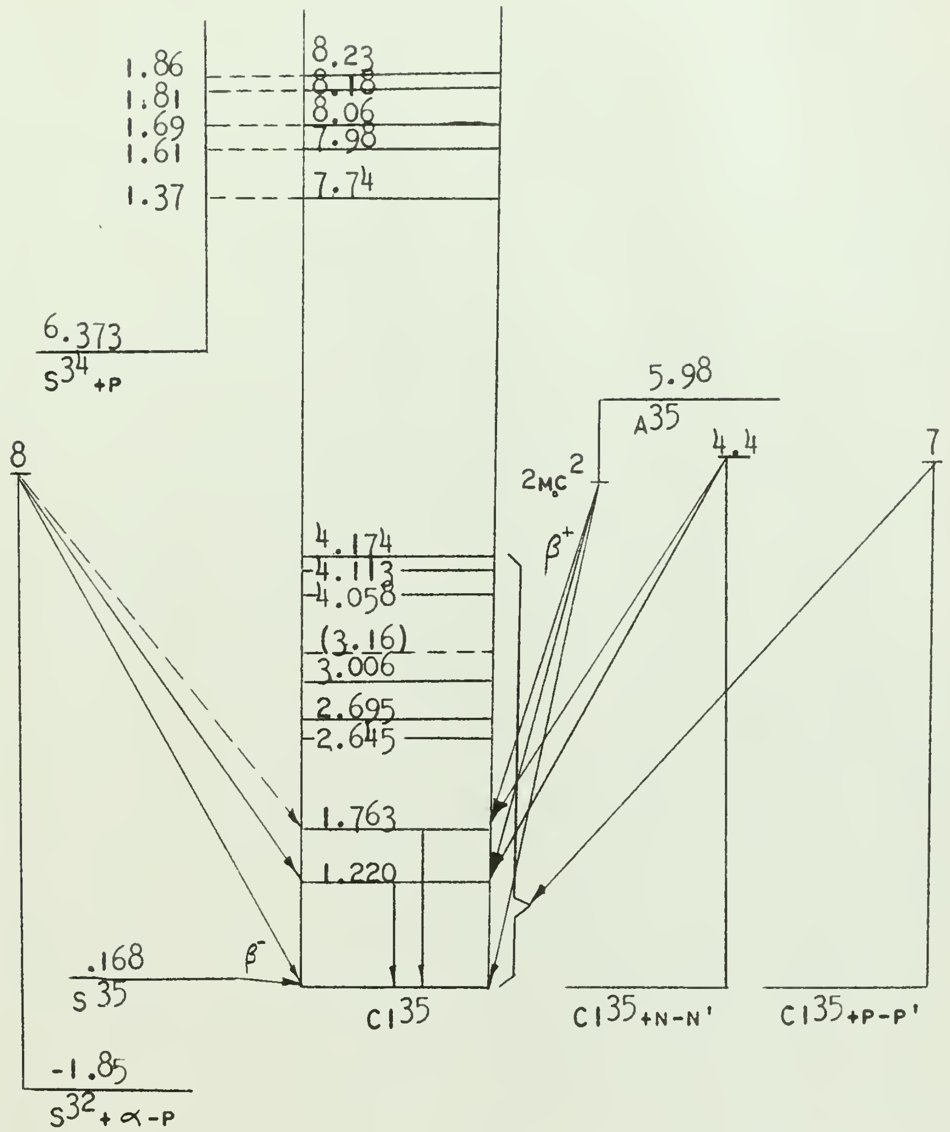


FIGURE 5. RESONANCE LEVELS OF Cl^{35}.

3. Equipment[1]

The energy of the proton beam from the Van de Graaff generator is resolved by means of a 25-degree electromagnetic analyzer which is calibrated in terms of proton energy versus magnet current. In the energy range of 800 to 1950 kev, covered during this investigation, the relation between beam current and magnet current is almost linear, so that adjacent calibration points can be connected by a straight line. It is noted that the energy of the beam is subject to the stability of the magnet current, and evidence will be described which indicates that this current is subject to drift. However, the scanning rate for an energy range can be controlled so that it is possible to proceed in steps of less than 0.5 kev for locating individual resonance peaks.

Regulation of the number of protons hitting the target per bombardment is accomplished by means of a current integrator which utilizes a capacitor to cut off the beam after a selected amount of charge has been received at the target, rather than after a selected period of bombardment.

The gamma yield from bombardment was detected by means of a thallium-activated sodium iodide crystal mounted on a photomultiplier tube. The signals from the photomultiplier were passed to as many as three non-overloading amplifiers which were capable of either integral or differential pulse discrimination. The signals from each amplifier were counted by a conventional scaler. The undiscriminated signals from one of the amplifiers were passed to an oscilloscope for visual presentation, and a Polaroid camera was used to record pulse height distribution at selected energies.

1 See Fig. 12, Analysis Equipment Schematic Diagram

Certain unconventional components of the investigative equipment are described in Appendix II.

4. Preparation of the Targets

Pure sulfur, melting point 112°C, is quickly evaporated by the heat generated by proton beams of the order of intensity of those required for this investigation. Consequently, enriched sulfur was obtained in the form of cadmium sulfide, which sublimes in pure nitrogen at 1750°C. Thus the stability of this material under conditions of proton bombardment is undoubtedly better than that of natural sulfur, though it was discovered that the cadmium sulfide required constant cooling during use. The method of cooling is described in Appendix I.

The cadmium sulfide obtained in powder form is not convenient as such for targets for proton bombardment. The method used for preparing targets from powdered material is a modification of the standard vacuum plating technique, and is described in Appendix II.

5. Experimental Methods

Substances which were expected to contribute gamma yields during the proton bombardment of the enriched material include the following:

A. Isotopes of sulfur in the enriched CdS:

S^{32}	62%
S^{33}	0.8%
S^{34}	37.2%
S^{36}	"trace"

B. F^{19}, which primarily exhibits the reaction $F^{19}(p, \alpha, \gamma)O^{16}$. The product nuclide O^{16*} in this reaction emits relatively intense gammas of 6.13, 6.90, and 7.12 Mev predominantly, energies which are of the same order of magnitude as the ground state transition radiation from the $S^{34}(p, \gamma)Cl^{35}$ reaction. This contaminant was present in varying amounts on all of the targets and unfortunately exhibits a number of relatively high resonances throughout most of the energy range of this investigation. The origin of the fluorine was not established. It is possible that the tantalum discs carrying the CdS contained the substance, but blank targets cleaned in the same manner as those with the CdS, exhibited very little of this radiation. It may be significant that the targets of enriched CdS indicated considerably more fluorine than those with the natural compound, raising the possibility that the enriched material itself contains a certain amount of fluorine.

C. C^{12} and C^{13} are deposited on a target during the course of bombardment. Apparently this carbon results from the minute amount of diffusion pump oil that is able to "creep" into the system, for spots of carbon blackening were more noticeable on targets which had been bombarded in relatively poor vacuum. The broad 1.698 Mev resonance

of the $C^{12}(p,\gamma)N^{13}$ reaction yielding gammas of 3.51 Mev was always discernible in various intensities, and it is considered that this reaction contributed to the general increase in background radiation observed throughout the entire upper portion of the energy range to 1.9 Mev. This is illustrated in Figures 9 and 10. On the other hand, it is not certain whether all of the several known resonances for the $C^{13}(p,\gamma)N^{14}$ reaction were observed consistently, because of the low relative abundance of C^{13} (about 1.1%) and the low cross-sections for the resonances, usually less than 0.1 millibarn.

The following methods were employed for determining whether observed resonances should be attributed to $S^{34}(p,\gamma)Cl^{35}$ reactions:

A. The energy range was traversed using targets of cadmium sulfide with natural sulfur, prepared by bubbling hydrogen sulfide into cadmium nitrate and separating the filtrate with a centrifuge. The relative magnitudes of resonances observed using these targets were compared with the yields obtained using the enriched material to determine whether possible resonances due to S^{34} reactions exhibited increased yields with the enriched targets.

B. The energy range was again traversed using blank targets which had been treated exactly the same as the cadmium sulfide targets, except for the actual coating. This technique provided an indication of the order of magnitude of the background yield, but it was not conclusive in revealing the amount of fluorine contamination on the targets. Figure 7. shows the yields from the 873 and the 935 kev fluorine resonances compared with those observed using targets of enriched material.

C. Two and sometimes three amplifiers with appropriate integral or differential biases were used to separate contaminant radiation from

the primary gammas of the S^{34} resonance reactions. This technique can be used for separating gammas due to Cl^{33} and N^{13}, and those from certain N^{14} levels, but it was not considered that the calibration of the amplifiers was sufficiently accurate for separating the radiation from O^{16*}. The technique is also limited by the fact that it only allows identification of the yields of the primary radiation from the S^{34} reactions which are energetically distinct from fluorine reactions, and it is not useful for identifying cascade radiation from the S^{34} reactions.

d. The most reliable means available for distinguishing the O^{16*} de-exciting radiation from that due to Cl^{35*} was photographic analysis of resonance radiation. As illustrated in Figure 6(a), the gamma signature of the $F^{19}(p,\alpha,\gamma)O^{16}$ reaction is relatively distinct, and it is proton energy-independent throughout the range of this investigation. However, it is noted that the O^{16*} gamma signature is only an approximate energy calibration for unknown radiation, for the following reasons:

(1) The oscilloscope presentation is not linear.

(2) The vertical scale on the oscilloscope exhibited a tendency to drift, and on one occasion this amounted to approximately 15% over a period of an hour. The source of the drift could have been either in the oscilloscope itself or in the pulse height of the incoming signal from the amplifier or the photomultiplier.

Resolution and Calibration of the Equipment

Based on observation of the resonance "spikes" of aluminum used for calibrations, it is considered that the rated resolution of the proton beam of 0.2%, or two kev at one Mev, is not exceeded. The influence of the "drift," discussed in the succeeding paragraph, on the observed widths

OF THESE SPIKES, WAS PROBABLY NOT APPRECIABLE, SINCE THE PEAKS OF THE SPIKES USUALLY COULD BE DEFINED BY NOT MORE THAN FOUR READINGS AT INTERVALS OF APPROXIMATELY 0.5 KEV, REQUIRING LESS THAN A MINUTE AND A HALF. THE THICKNESS OF THE ALUMINUM COATING ON THE TARGET WAS NOT KNOWN, BUT THE TOTAL PEAK WIDTHS DUE TO THE WIDTH OF THE BEAM PLUS THE THICKNESS OF THE TARGET WERE SOMETIMES AS NARROW AS 2 KEV, SO THAT THE BEAM WIDTH COULD NOT HAVE EXCEEDED THIS.

BOTH ALUMINUM AND FLUORINE TARGETS WERE USED FOR CALIBRATION, AND THE SHAPES AND SPACINGS OF THE LATTER WERE CORRELATED WITH O^{16*} GAMMA SIGNATURES WHICH COULD ALWAYS BE IDENTIFIED ON THE CADMIUM SULFIDE TARGETS. HOWEVER, IT IS CONSIDERED THAT THE INFLUENCE OF DRIFT ON THESE CALIBRATIONS WAS THE MOST SERIOUS LIMITATION TO THE ACCURACY OF THE DETERMINATIONS OF THE RESONANCE ABSORPTION LEVELS. THE OBSERVED DRIFTS WERE PROBABLY DUE BOTH TO SMALL FLUCTUATIONS IN THE MAGNET CURRENT SOURCE AND TO STRAYING OF THE REFERENCE CURRENT USED WITH THE POTENTIOMETER. THESE TWO CONTRIBUTIONS TO DRIFT COULD BE APPROXIMATELY RESOLVED AT ANY SPECIFIED POINT FOR A GIVEN TIME INTERVAL; BUT THE DRIFT RATE WAS NOT CONSTANT EITHER IN MAGNITUDE OR DIRECTION. ACCORDINGLY THE MOST REASONABLE WAY TO TREAT THE DRIFT APPEARED TO BE TO ESTABLISH AT LEAST TWO CALIBRATION POINTS FOR EACH HYSTERESIS LOOP OF THE ELECTROMAGNET AND REFER ALL ENERGIES OBSERVED FOR THIS LOOP TO THIS SLOPE. THE SLOPE WAS OBVIOUSLY NOT PRECISELY CONSTANT, AS IS OFTEN ASSUMED. THE REPORTED ENERGIES SHOULD THEN BE MODIFIED BY AN ARBITRARY ACCURACY WHICH REFLECTS THE MAXIMUM DRIFTS OBSERVED. THE ACCURACY OF THIS INVESTIGATION, CONSIDERING ONLY DRIFT AND BEAM RESOLUTION, WAS POSTULATED AS $\pm$ 4 KEV FOR EACH OBSERVED ENERGY.

Widths of Resonance Peaks

After calibrating carefully and allowing for drift as described in the foregoing section, the resonance yield must be made as narrow as possible so that the peak can be clearly defined. Besides drift, the three factors which influence yield width are beam resolution (discussed above), actual resonance width, and target thickness. Thus it is clear that the targets used for the final determination of resonance proton energies should be as thin as practicable while still allowing an appreciable intensity of yield. In coating the final targets, two and one-half milligrams of cadmium sulfide were used for approximately 65 cm^2 of surface, including the wasted areas on the well, described in Appendix I. It is noted that for "rough scanning" of energy levels, photographing resonance peaks, and other procedures that require protracted bombardment of a target, 10 milligrams per 65 cm^2 produces fairly rugged targets, though the resonance widths observed are relatively coarse.

Amplitudes of Resonances

The observed amplitudes of yield peaks depend on such factors as the following:

(a) the integrator capacitance selected.

(b) Calibration and bias settings of the amplifiers.

(c) Thickness of the targets.

(d) Location of the crystal relative to the targets.

(e) Intensity of the background.

From the foregoing it is apparent that the absolute values of the resonance amplitudes are not relevant except as related to other resonances observed with the same target during the same run. The plots in Figures 7 through 10 have been normalized to a reference plot, so that the resonances shown thereon are approximately to scale.

6. Results

Figure 7

The two intense fluorine peaks at E_p of 873.5 and 935 kev were observed with approximately correct relative yields on all targets run in this energy range. However, they were carefully searched for low intensity S^{34} resonances, because:

(a) The peaks obtained with CdS^{34} targets were separated slightly more than the same resonances on pure fluorine targets.

(b) The shapes of the CdS^{34} resonances were not regular like the natural fluorine peaks, particularly near the leading edges.

(c) The width-amplitude ratios of the CdS^{34} fluorine resonances were consistently greater than the same ratios for pure fluorine targets. However, Figure 6(a), typical of several obtained from these peaks, indicates that any S^{34} resonances therein are well masked by the fluorine and were not resolved by the techniques described herein.

The peak at E_p of 1015 kev is considered to be due to S^{34} for the following reasons:

(a) There are no known contaminants in this energy range.

(b) The peak is relatively higher with CdS^{34} targets than with CdS^{32} or CdS^{33}.

(c) Figure 6(b) indicates that the calculated ground state transition gammas of 7.37 Mev are probably present, as well as possible cascades with gammas of about 5.7 and 1.7 Mev.

The low yield resonance at 1155 kev was observed only with enriched targets, as would be expected if it were due to S^{34}. However, resolution in this energy range is difficult because of a high background of radiation from a low fluorine level at 1176 kev with a half-width of 130 kev.

It is also noted that there is a reported C^{13} resonance at 1160 kev, though this may not have appeared due to its low cross-section of 0.56 millibarns.

Figure 8

The relatively intense resonance at E_p of 1206 kev is considered to be due to S^{34} for the same reasons as those set forth for the peak at 1015 kev above. It is noted on Figure 6(c) that the primary gammas of approximately 7.6 Mev are faintly discernible, but most of the radiation is cascade below 4.5 Mev.

The peaks at E_p of 1346 and 1378 kev are known to be predominantly fluorine resonances, for their relative intensities and their separation are consistent with results obtained with pure fluorine targets. However, considerable efforts were made to try to resolve them for the following reasons:

(a) A S^{34} resonance has been reported at 1370 kev by Hanscome and Malich.

(b) The definition of neither of the peaks was nearly as clear-cut as with fluorine targets.

(c) With thin targets a small spike was sometimes observed just below the 1346 kev peak, and another small spike was always apparent nearly at the top of the 1378 kev peak. Various photographs like Figure 6(d), taken near the 1378 peak, were not conclusive, for the 6.13, 6.9, and 7.12 gammas from O^{16*} are very intense.

It is speculated that there could be cascade gammas of approximately 3 and 4 Mev, but it is not claimed that the 1370 S^{34} resonance was actually observed. It is noted that drift was very apparent during this part of the investigation. On one occasion the galvanometer drifted approximately 4 kev at a constant setting during the five-minute interval

REQUIRED TO CHANGE TARGETS FOR PHOTOGRAPHING.

It is possible that the small peaks at E_p of 1449 and 1479 kev are due to S^{34}, for they were not observed with CdS^{32} targets, and their respective photographs are not similar to any observed gamma signatures of possible contaminants. Figure 6(e) indicates possible high energy radiation of the calculated 8 Mev, with several cascade gammas, e.g., 6, 5, 4, 2.3, etc. Figure 6(f) shows no radiation above approximately 6.5 Mev, with numerous possible cascades below this.

For reasons discussed for other peaks above, the resonance at 1523 kev is considered to be due to S^{34}. It is noted that the yield is lower for natural targets than for enriched, and this resonance is not reported at all during the S^{33} investigation by Gaehler and Knipp. Figure 6(g) indicates maximum gammas of approximately 7 Mev, with numerous cascades.

<u>Figure 12</u> (It is noted that this energy region extends only to about 1950 kev)

The small peaks at E_p of 1626 kev did not appear regularly, frequently being masked by the broad 1697 C^{12} resonance, and it was not photographed. However, it was also observed during the Gaehler and Knipp investigation of S^{33} resonances, and might be due to S^{33} or S^{34}. It is noted that Hanscome and Malich reported a S^{34} resonance at 1610 kev.

The reported resonances of C^{12} at 1697 kev and of S^{32} at 1900 kev were regularly observed and identified. However, these two peaks provide a high background in the region between them which makes resolution of small peaks therein quite difficult. Definite small peaks were observed at 1731, 1758, 1768, 1787, 1798, 1841, and 1942 kev, and Figure 6(h) is typical of these. It shows a relatively large amount of radiation with energy greater than 8 Mev, sufficient to be due to S^{34} resonances, and

NUMEROUS CASCADES. HOWEVER, IT IS CONSIDERED THAT FURTHER WORK IN THIS REGION WOULD BE REQUIRED TO RESOLVE AND IDENTIFY ALL OF THESE PEAKS, DUE TO THEIR RELATIVELY LOW YIELD AND CLOSE SPACING.

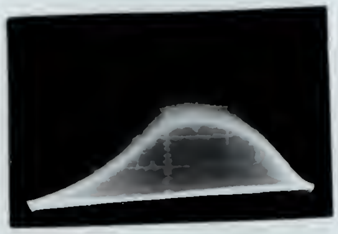
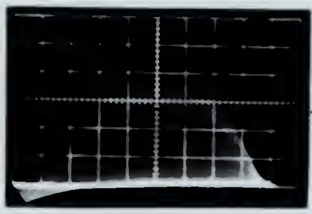


Fig. 6(a). γ-O^{16*}

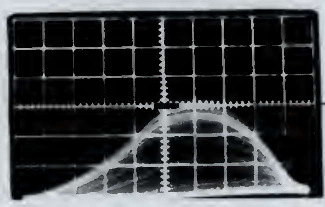


6.9 Mev

Fig. 6(b). γ-Cl^{35*}
Ep = 1015 kev

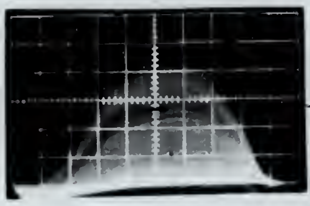
Mev

Fig. 6(c). γ-Cl^{35*}
Ep = 1206 kev



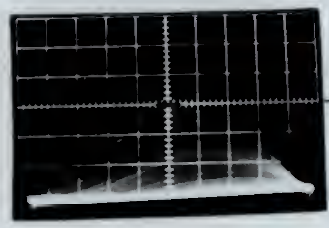
6.9 Mev

Fig. 6(d). γ-Cl^{35*}
Ep = 1375 kev



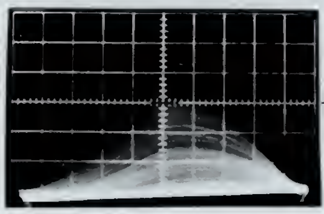
6.9 Mev

Fig. 6(e). γ-Cl^{35*}
Ep = 1449 kev



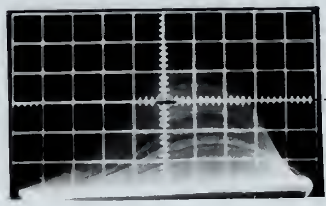
6.9 Mev

Fig. 6(f). γ-Cl^{35*}
Ep = 1479 kev



6.9 Mev

Fig. 6(g). γ-Cl^{35*}
Ep = 1523



6.9 Mev

Fig. 6(h). γ-Cl^{35*}
Ep = 1798 kev

Figure 6. Gamma Spectra for (p, γ) Reactions

7. Conclusions

1. The observed resonances which are most likely to be due to the $S^{34}(p,\gamma)Cl^{35}$ reaction are the following:

E_p (kev)	Relative Yield	Half-width (kev)
1015 ± 4	1.5	9
1206 ± 4	13.5	5
1523 ± 4	4.5	8

2. Observed resonances which are probably due to the $S^{34}(p,\gamma)Cl^{35}$ reaction are:

E_p (kev)	Relative Yield	Half-width (kev)
1155 ± 4	0.25	undetermined
1449 ± 4	1.0	undetermined
1469 ± 4	1.2	undetermined

3. Possible resonances due to the $S^{34}(p,\gamma)Cl^{35}$ reaction, which require more refined definition for positive identification, are the following:

E_p (kev)	Relative Yield	Half-width (kev)
873 ± 10	undetermined	undetermined
935 ± 10	"	"
1345 ± 8	"	"
1375 ± 5	"	"
1616 ± 4	0.3	"
1731 ± 4	2.2	"
1758 ± 4	2.0	6
1768 ± 4	1.6	undetermined
1787 ± 4	1.4	"
1798 ± 4	2.5	2
1841 ± 4	2.0	undetermined
1942 ± 4	1.5	"

APPENDIX I

TARGET COATING PROCEDURE

The material used for the targets was cadmium sulfide in powder form, in which the sulfur had been enriched from naturally-occurring 4.2% of S^{34} to approximately 37.2% of S^{34}. One advantage of using this compound for proton bombardment is that it remains stable at relatively high temperatures, so that melting it with the heat generated by the proton beam is not a problem, as is the case with pure sulfur. The only figure available describing the melting temperature of cadmium sulfide is from the Handbook of Chemistry and Physics, which gives 1750°C at 100 atm. pressure. Apparently in the vacuums of 10^{-5} - 10^{-6}mm.Hg at which the targets were both coated and bombarded, the cadmium sulfide sublimes, rather than melts. Other advantages of this compound are that it is relatively stable under standard conditions and it is not hygroscopic. The most important disadvantage is that after it has sublimed due to heating, cadmium sulfide will only deposit on surfaces which are at very low temperatures. This troublesome characteristic was discovered by accident, and it may be the reason that cadmium sulfide has not been more widely used as target material by other investigators of sulfur resonances.

The basic procedure used for preparing the cadmium sulfide targets was the conventional vacuum plating technique, in which the cadmium sulfide sample is heated to sublimation temperature in a vacuum of approximately 10^{-5}mm.Hg. The target "carriers" were thin tantalum discs approximately 1.5 cm. in diameter, which had been cleaned by using both nitric acid and acetone in attempting to minimize the amount of fluorine contamination which apparently no amount of cleaning can completely

ELIMINATE. THE PRINCIPAL INNOVATION TO CONVENTIONAL TECHNIQUE WAS IN COOLING THE TANTALUM DISCS SO THAT THE CADMIUM SULFIDE MOLECULES WOULD "STICK" THEREON AFTER SUBLIMATION. FOR THIS PURPOSE, A STAINLESS STEEL LIQUID AIR TRAP WAS PREPARED. THE DISCS WERE SECURED PERIPHERALLY AROUND THE WELL BY WEDGING THEM BETWEEN ADJUSTABLE BANDS OF LUCITE SO THAT THE BACK OF EACH DISC WAS FLAT AGAINST THE SURFACE OF THE WELL FOR MAXIMUM HEAT CONDUCTION. EXCEPT FOR THAT PORTION WHICH CONTAINED THE DISCS, THE EXTERIOR SURFACE OF THE WELLWAS INSULATED BY LUCITE SO THAT NONE OF THE CADMIUM SULFIDE WOULD BE WASTED. IT HAD BEEN PREVIOUSLY NOTED THAT A SMALL AMOUNT OF CARBON CONTAMINATION WAS IN EVIDENCE ON TARGETS PREPARED IN THIS MANNER. A POSSIBLE SOURCE OF THIS CARBON WAS THE DIFFUSION PUMP OIL WHICH APPARENTLY ADHERES TO THE COLD SURFACES OF THE WELL AND THE DISCS FROM THE TIME THE COOLING IS COMMENCED, BEFORE THE CADMIUM SULFIDE SUBLIMATION OCCURS. IN AN ATTEMPT TO REDUCE THE AMOUNT OF THIS CONTAMINANT, A PISTON WAS PLACED INSIDE THE WELL AT A HEIGHT JUST ABOVE THE LOCATION OF THE TOPMOST RING OF DISCS. A $\frac{1}{2}$" VERTICAL SLOT WAS CUT IN THE LUCITE INSULATION ON THE OUTSIDE OF THE WELL. THUS WHEN LIQUID AIR WAS FIRST POURED IN, THE PISTON PREVENTED IT FROM DROPPING TO THE BOTTOM, SO THAT THE INITIAL COOLING OCCURRED BETWEEN THE PISTON AND THE TOP OF THE WELL. IT IS HOPED THAT BY THIS DEVICE THE CARBON CONTAMINANT COULD BE INDUCED TO DEPOSIT ON THE SURFACE EXPOSED BY THE SLOT, SO THAT BY THE TIME THE VACUUM INSIDE THE GLASS BELL WAS SUFFICIENTLY LOW TO COMMENCE HEATING THE CADMIUM SULFIDE, MOST OF THE CARBON SHOULD HAVE BEEN REMOVED. BEFORE THE CADMIUM SULFIDE WAS HEATED, THE PISTON WAS REMOVED AND THE VACUUM PLATING PROCEEDED CONVENTIONALLY. TO FACILITATE OBSERVATION OF THE RELATIVELY SMALL QUANTITY OF MATERIAL, A MAGNIFYING MIRROR WAS PLACED BESIDE THE "BOAT", ORIENTED SO THAT THE OPERATOR OF THE HEAT CONTROL COULD

OBSERVE THE TARGET MATERIAL. IT WAS NOTED THAT THE ARRANGEMENT OF THE DISCS RELATIVE TO THE CADMIUM SULFIDE NEED NOT BE LINE-OF-SIGHT, SINCE TEMPERATURE RATHER THAN LOCATION IS THE GOVERNING FACTOR IN PLATING THIS MATERIAL. APPROXIMATELY 30 DISCS WERE COATED PER RUN. CARBON CONTAMINATION WAS ALMOST ELIMINATED BY THE ABOVE PROCEDURE, BUT A SIGNIFICANT AMOUNT OF FLUORINE STILL REMAINED.

APPENDIX II

TARGET COOLING ASSEMBLY

Use of CdS as a target material required certain modifications to the target section of the Van de Graaff generator. Because of the thermal instability of CdS targets under proton bombardment, some means of cooling the target had to be devised (See Fig. 11). A 6" pyrex test tube (O.D. = $\frac{1}{2}$") open at both ends was inserted in the target chamber of the generator by means of a high vacuum metal-to-glass coupling. The CdS coated tantalum discs, with a sealing gasket, were placed on the opposite end to be held in place by pressure differential. A stream of cooled air was circulated around the back of the exposed tantalum disc. It was considered that this provided good heat conduction, without interfering with gamma transmission. The integrator current was collected by a conductor held snugly against the tantalum with a transparent celluloid cover, providing electrical insulation. The complete assembly was inserted into the well of a 2"X2" thallium-activated sodium iodide crystal mounted on a photomultiplier tube oriented parallel to the beam.

The arrangement proved to be satisfactory even though the tantalum-to-glass gasket seal had to be replaced frequently. The constant cooling of the target allowed beam currents of up to 8 μa for the long periods of bombardment necessary for photographic analysis. On several occasions when the cooling of the target had been inadvertantly interrupted, the yield was observed to decrease to background under continued bombardment at a constant energy, illustrating the necessity for this device.

TABLE I

Reaction	Q (Mev)	Reference
$S^{32}(p,\gamma)Cl^{33}$	+2.285	1
$S^{33}(p,\gamma)Cl^{34}$	+5.12	1
$S^{34}(p,\gamma)Cl^{35}$	+6.373	1
$S^{36}(p,\gamma)Cl^{37}$	+8.46	1
$S^{32}(p,n)Cl^{32}$	-13.8	1
$S^{33}(p,n)Cl^{33}$	-6.360	1
$S^{34}(p,n)Cl^{34}$	-6.30	1
$S^{36}(p,n)Cl^{36}$	-2.0	1
$S^{32}(p,d)S^{31}$	-12.84	
$S^{33}(p,d)S^{32}$	-6.42	
$S^{34}(p,d)S^{33}$	-9.19	
$S^{36}(p,d)S^{35}$	-7.69	
$S^{32}(p,\gamma)P^{29}$	-4.197	1
$S^{33}(p,\gamma)P^{30}$	-1.531	1
$S^{34}(p,\gamma)P^{31}$	-0.611	1
$S^{36}(p,\gamma)P^{33}$	+0.5	1

TABLE II

List of Equipment

Three - Non- Overload Amplifiers
Model N302
Hamner Electronics Company, Inc.

Three - Glow tube Scaler
Atomic Instrument Corporation
Model 1283

Type 531 Oscilloscope
Tectronix, Inc

Photomultiplier Tube
6292
Dumont

Polaroid Land Camera
Type 2620 - Shutter F/2.8
Polaroid Corporation

BIBLIOGRAPHY

1. C. Van der Leun: Thesis, "Investigations with Light Nuclei with (p, γ) Reactions" Utrecht University, Utrecht, Nederland (1958)

2. P. M. Endt, (private communication)

3. T. D. Hanscome and C. W. Malich, Phys. Rev. 82, 304(A) (1951)

4. T. D. Hanscome and C. W. Malich (private communication)

5. A. J. Ferguson and H. E. Gove, Phys. Rev. 91, 493(A) (1953)

6. J. W. Olness, W. Haeberli, and H. W. Lewis, Phys. Rev. 112, 1702 (1958)

7. P. M. Endt and C. M. Braams, Rev. Mod. Phys. 29, 683 (1957)

8. W. C. Roberts and D. H. Williams, Thesis, "Proton Resonances in Natural Silicon", USNPGS, (1958)

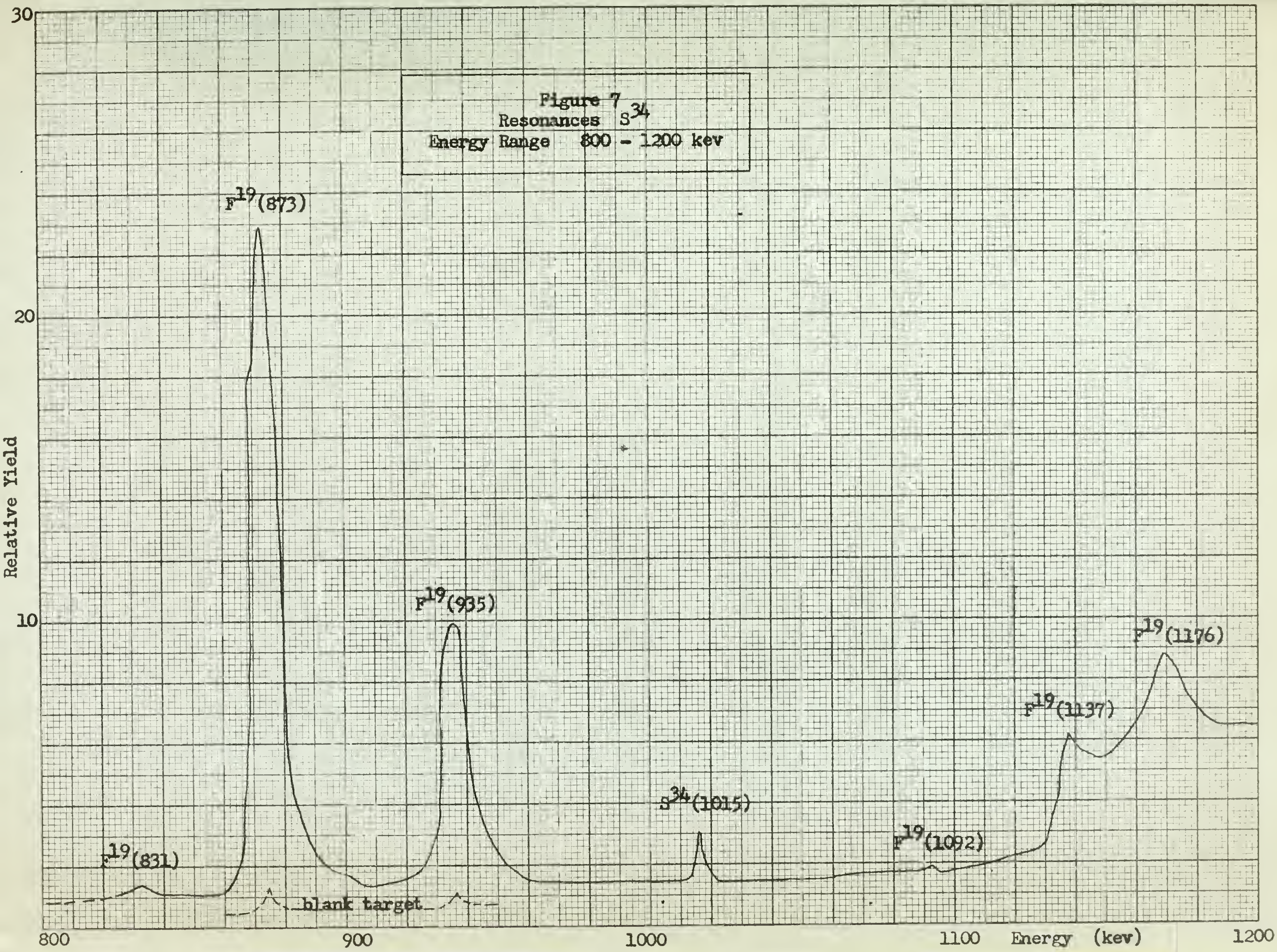


Figure 7
Resonances S^{34}
Energy Range 800 - 1200 kev
F^{19}(873)
F^{19}(935)
F^{19}(831)
S^{34}(1015)
F^{19}(1092)
F^{19}(1137)
F^{19}(1176)
blank target
Relative Yield
30
20
10
800
900
1000
1100
1200
Energy (kev)

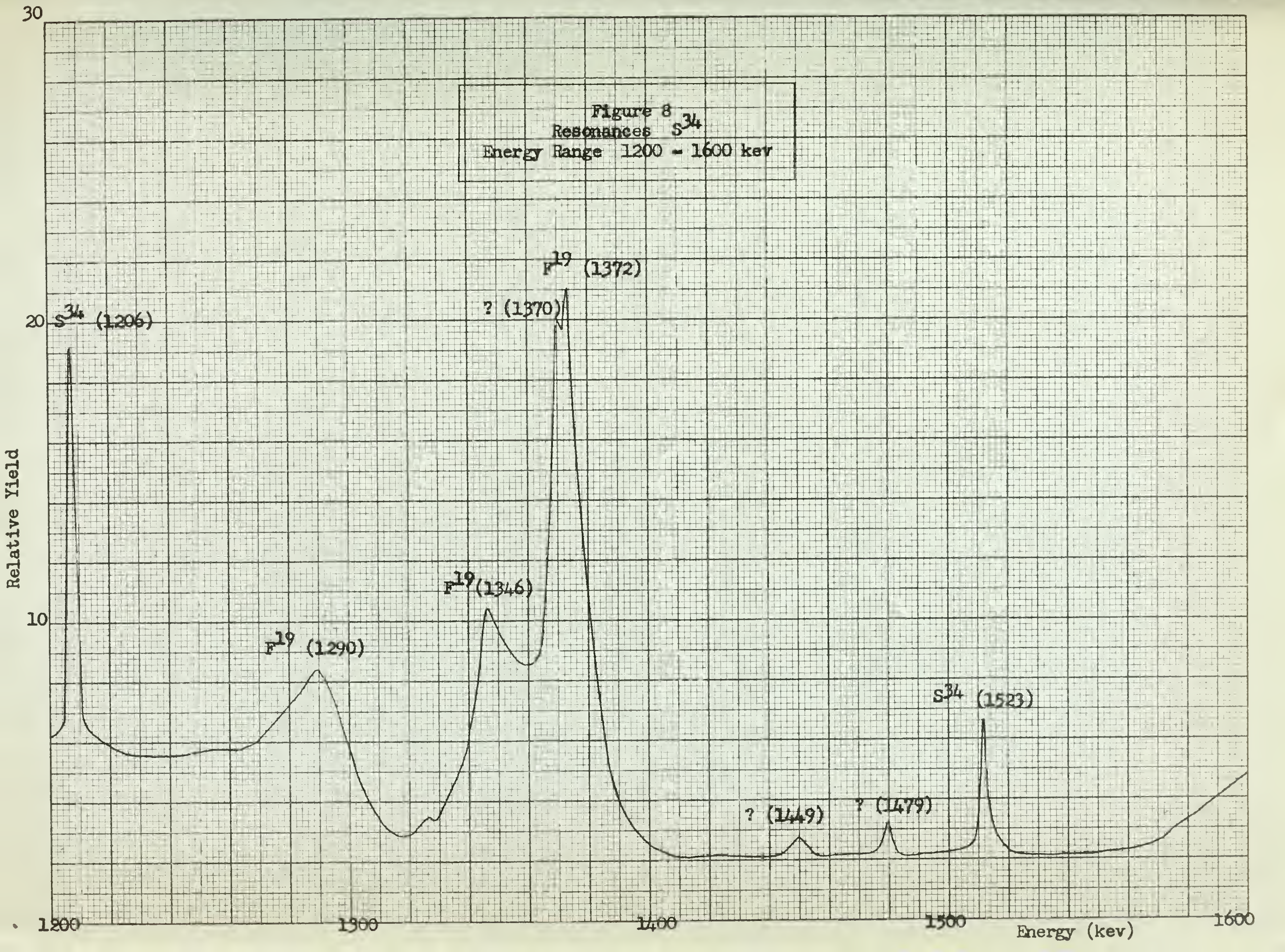


Figure 8
Resonances S34
Energy Range 1200 - 1600 kev
S34 (1206)
F19 (1290)
F19 (1346)
? (1370)
F19 (1372)
? (1449)
? (1479)
S34 (1523)
Relative Yield
30
20
10
1200
1300
1400
1500
1600
Energy (kev)

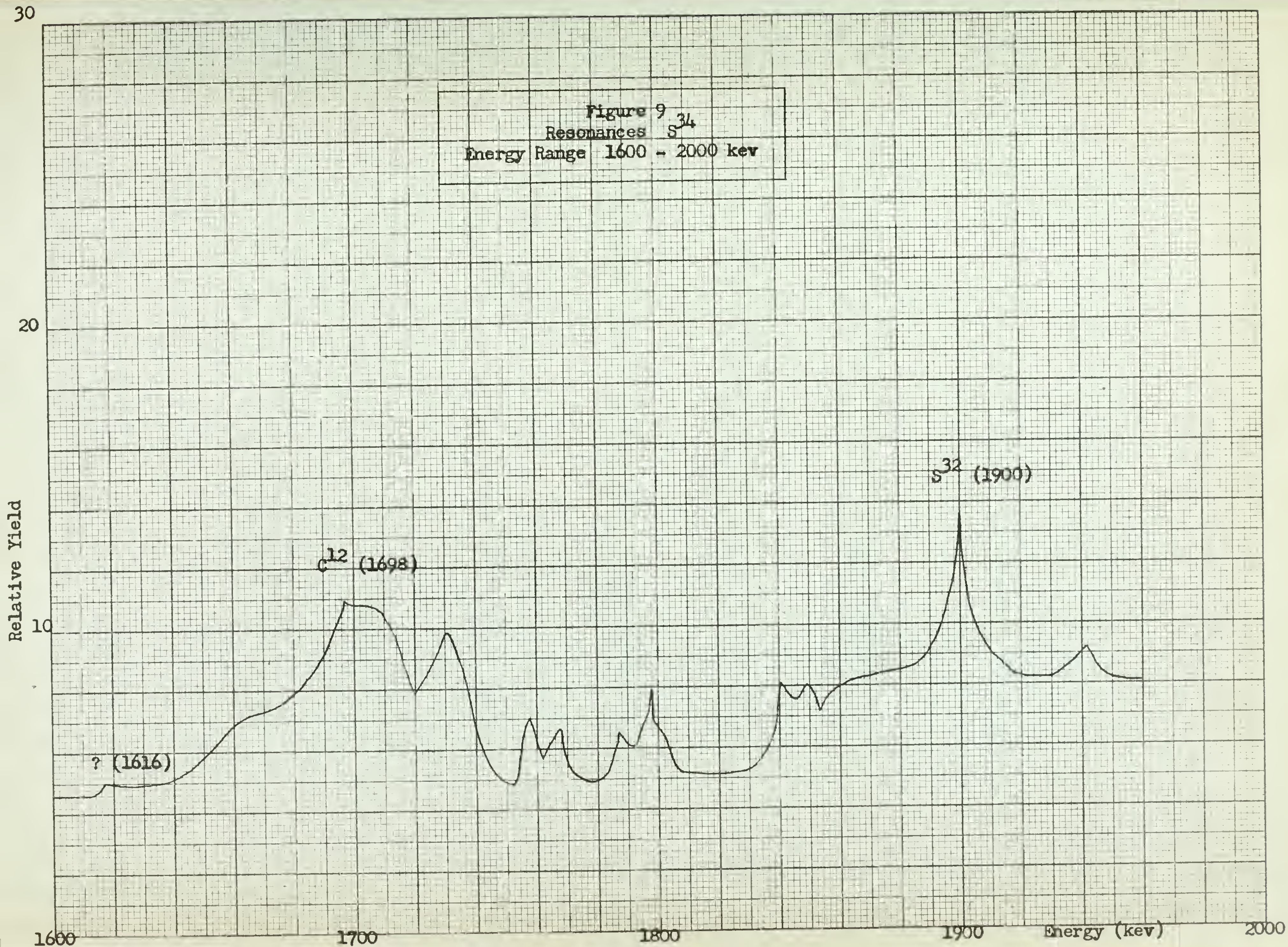
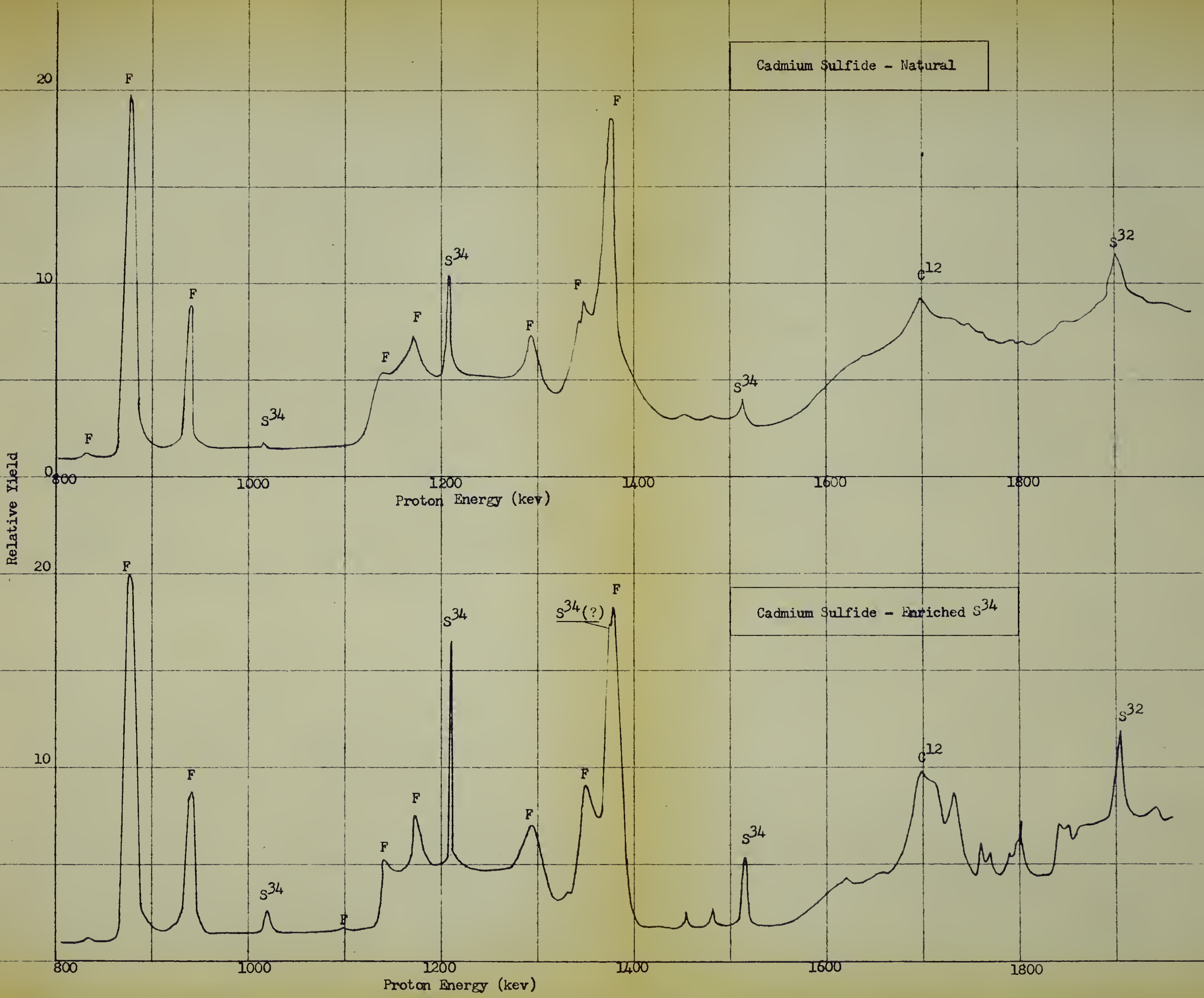


Figure 9
Resonances S^{34}
Energy Range 1600 - 2000 kev
? (1616)
C^{12} (1698)
S^{32} (1900)
Relative Yield
30
20
10
1600
1700
1800
1900
2000
Energy (kev)



Cadmium Sulfide - Natural
Cadmium Sulfide - Enriched S34
Relative Yield
Proton Energy (kev)
Proton Energy (kev)
F
S34
S34(?)
C12
S32
0
10
20
800
1000
1200
1400
1600
1800

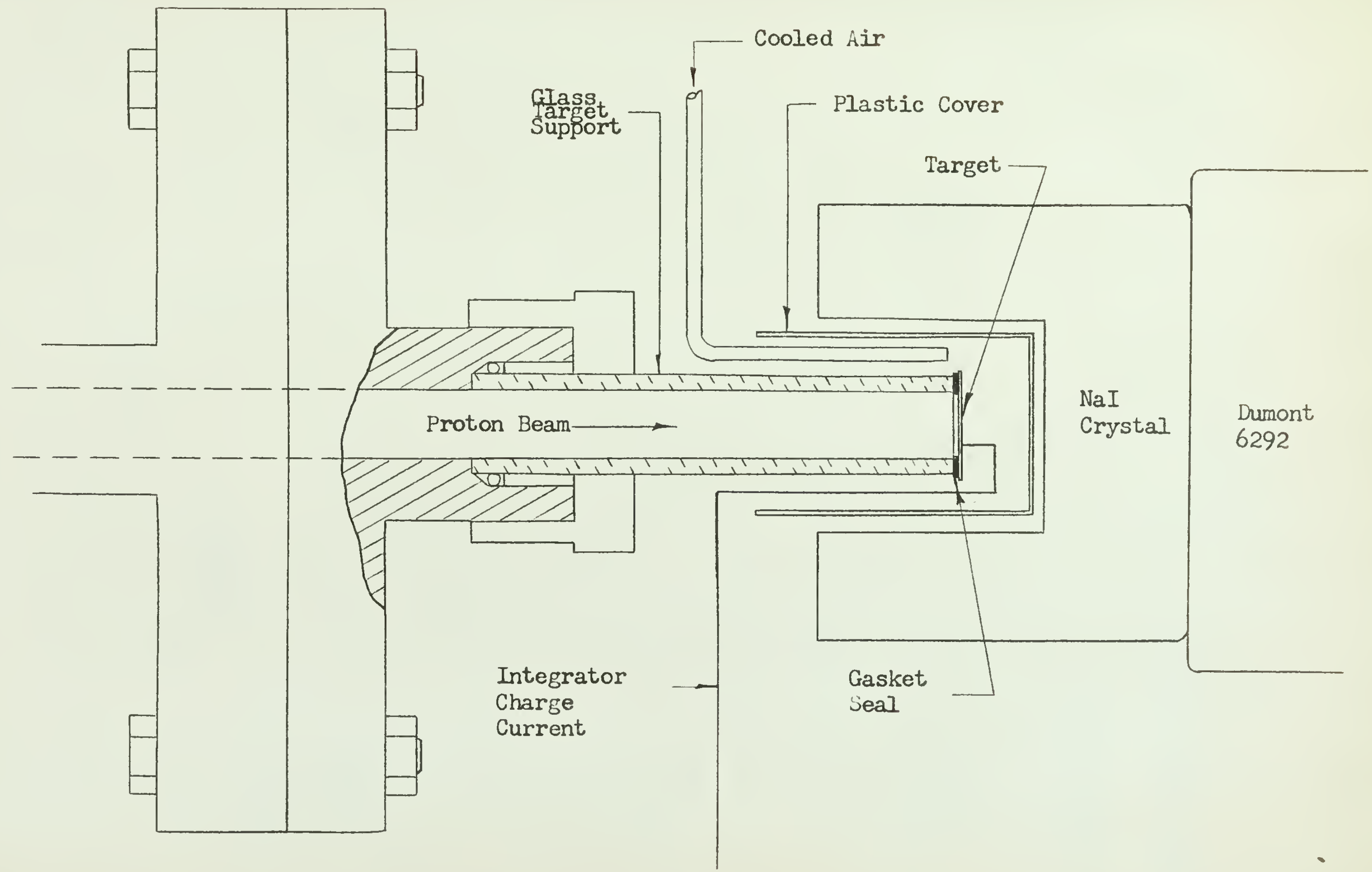


Figure 11. Target Section

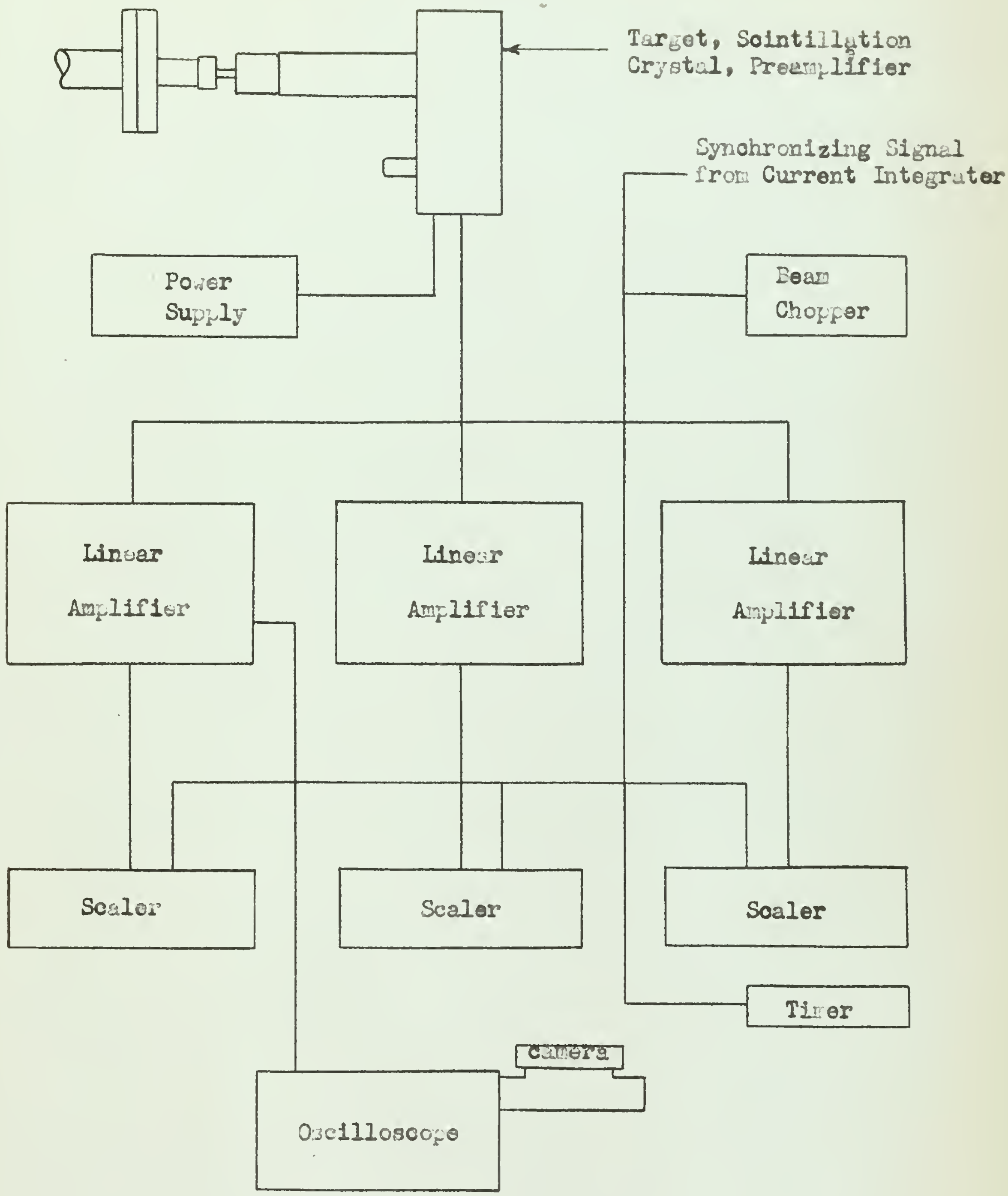


Figure 12. Analysis Equipment Schematic Diagram